

**MURKY**  
**ACS Software to Determine 3 Axis Attitude**  
**Without the Star Tracker**

**Sam Sirlin**  
**Tony Vanelli**  
**Sanjay Joshi**  
**Jim Alexander**  
**John Hench**

**May 1, 2000**

## Review Objectives

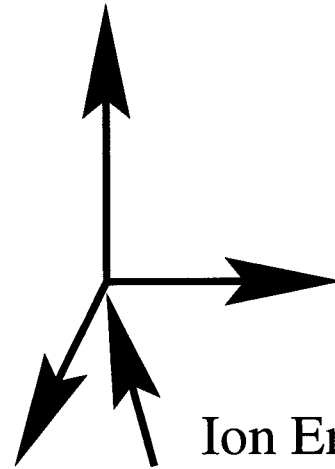
- Independant peer review of the effort
- How workable is the proposed solution?
- What improvements should be made?
- Concentrate on flight code, as opposed to ops or ground support.

## **Presentation Overview**

<b>1:30-2:00 Overview</b>	<b>Sam Sirlin</b>
<b>2:00-2:45 Estimator</b>	<b>Sanjay Joshi</b>
<b>2:45-3:30 Star ID</b>	<b>Jim Alexander</b>
<b>3:30-4:00 Discussion</b>	

# The Spacecraft

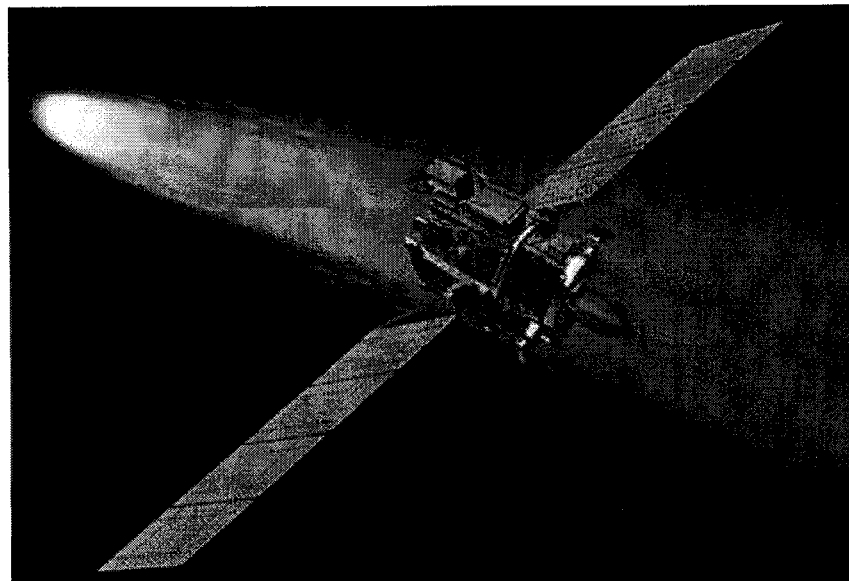
z, MICAS



y, Panel Gimbals

Ion Engine Thrust

x, SSA, HGA



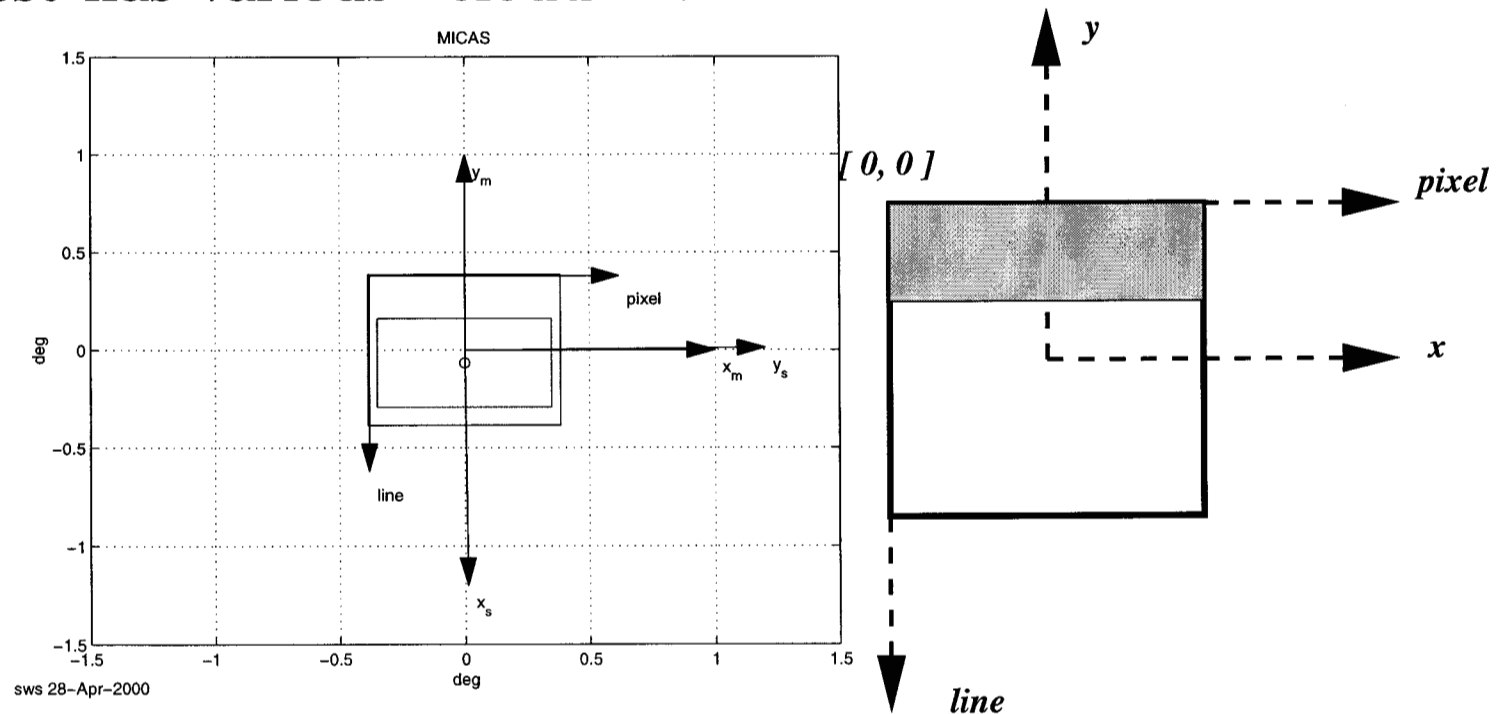
SWS-3

## The Problem

- No measurements from the SRU
- Need at least 2 celestial references to determine attitude
- Available equipment
  - 1 SSA, good to  $0.5^\circ$ , FOV  $\pm 64^\circ$
  - IMU, bias  $< 3^\circ/hr$ , stable to  $0.35^\circ/hr$  over  $1hr$
  - MICAS, CCD FOV  $\sim 0.75^\circ$ , various light problems; readout time about  $20s$ .
  - MICAS, APS FOV  $\sim 0.25^\circ$ , various light problems; readout time about  $2s$ .
  - AGC, apparently good to  $\sim 5^\circ$ ; has been used to close the loop through the ground and maintain HGA lock.

# MICAS CCD

- The field of view is  $0.75 \times -0.75^\circ$ , divided into  $1024 \times 1024$  pixels (about  $13\mu\text{rad}/\text{pixel}$ )
- Stray light is a problem
- The top 1/3 is unusable due to the “blowtorch”
- The rest has various “cloud” formations



## A Possible Solution

- Use the sun as one reference (SSA)
- Get one star from MICAS
- Initialize with ground in the loop, either using AGC or processing star data from MICAS
- Near conjunction, we have poor geometry (Sun and Earth are nearly in the same direction), so initialize (if necessary) using data collected with MICAS from a slow roll about the sunline

## IMU Biases

- **Given bias of  $3^\circ/hr = 1.45 \times 10^{-5} rad/s$** 
  - **Build up  $\Delta\theta = 0.3^\circ$  takes  $360s = 6min$**
  - **$180^\circ$  turn must be done at  $> 0.5^\circ/s = 8.7 \times 10^{-3} rad/s$**
- **Given perfect bias knowledge, unknown drift of  $0.35^\circ/hr$** 
  - **Build up  $\Delta\theta = 0.3^\circ$  takes  $4700s = 78min$**
  - **$180^\circ$  turn must be done at  $> 0.038^\circ/s = 6.7 \times 10^{-4} rad/s$**



## Existing ACS Software Architecture

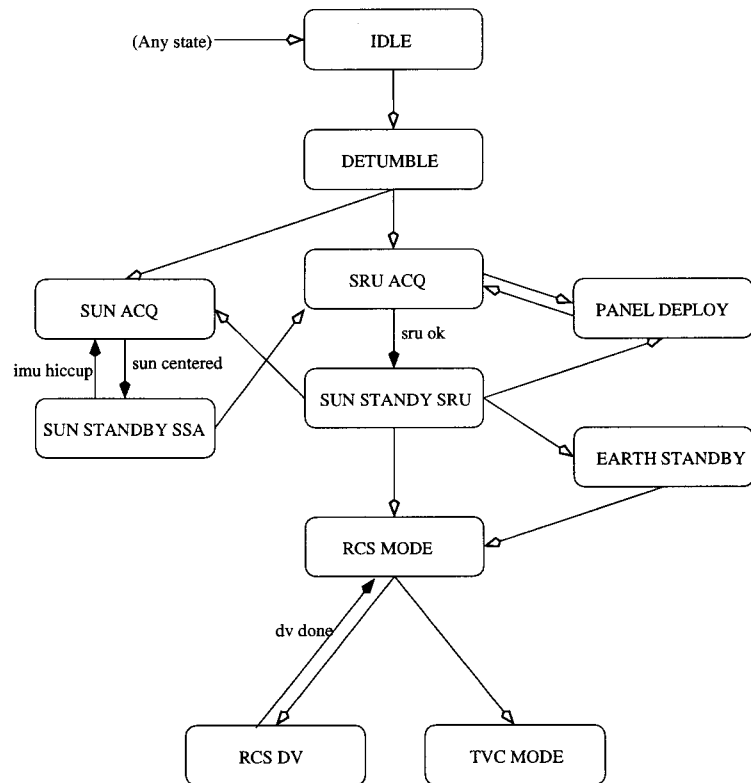
### ○ Code Modules:

- acm attitude commander/profiler
- ape attitude planner
- acs command interface
- ate attitude estimator
- bbc base body controller
- cmt constraint monitor
- gde Gimbal Drive Electronics manager
- imu IMU manager
- mdc mode commander
- rcs RCS manager
- sac solar array controller
- sru SRU manager
- srustandby SRU standby mode
- ssa sun sensor manager

## Existing ACS Software Architecture

- Code Modules (continued):
  - sunsrch      sun search mode
  - sunssa      sun standby ssa mode
  - tvc          thrust vector controller
  - rcsdv      RCS  $\Delta V$  controller

# Existing ACS Software Architecture



## KEY

- > Commanded Transition (ground/FP)
- > ACS automatic transition on detection of <condition>

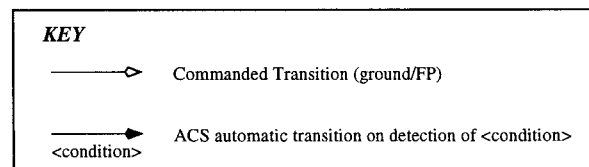
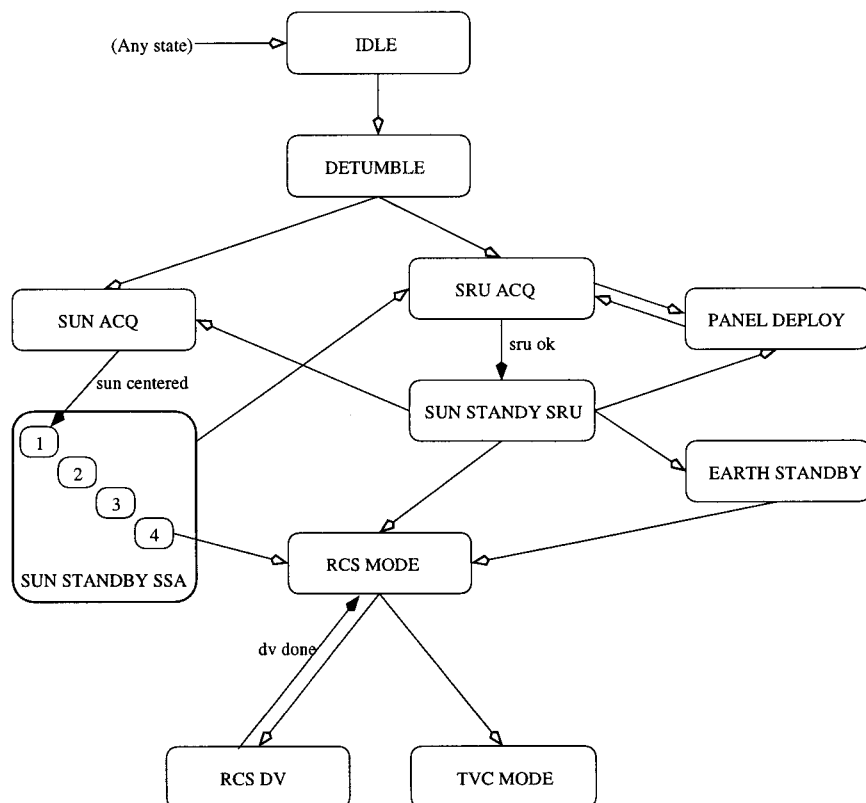
## New ACS Software Architecture - Status

- We began code development in January
- Now under change control
- The code is running in the testbeds
- Upload to the spacecraft on May 30, 2000

## New ACS Software Architecture

- New Code Modules:
  - murky      Murky Exec - request images, command turns, send data to Star ID, communicate with ATE  
4400 lines of code
  - sid      Murky Star ID - process images  
3700 lines of code
- Changes to Existing Code Modules:
  - ate      use the sun sensor, accept various new sensors  
2900 lines of code
  - sunssa      new logic for mode transitions  
1500 lines of code
  - various      new commands, parameters, autogenerated prototypes, prints, ids etc
- Code size +17655 since M3

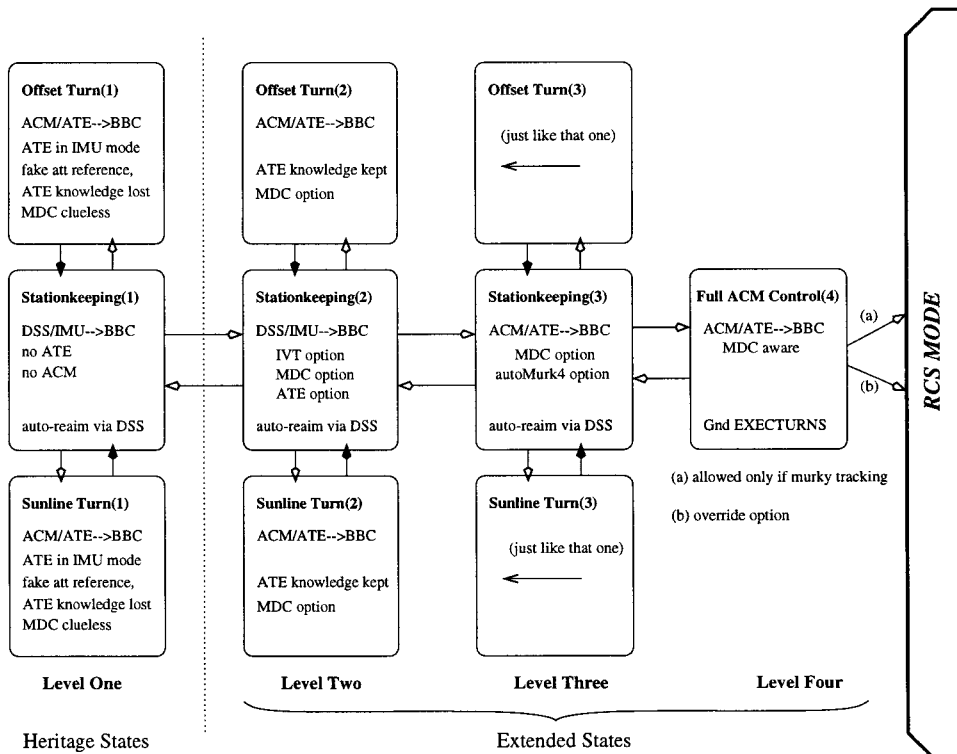
# New ACS Software Architecture



# New ACS Software Architecture

## SUN STANDBY SSA - extensions

(Continuous Rolls not shown)



## New ACS Software Architecture

- Acquisition - Murky requests two images

time (s)	event
7	clear micas buffer
	2 image requests sent
1-2	exposure $27 - 100ms + \text{overhead}$
	image tagged with current quaternion from ATE
1-2	exposure $27 - 100ms + \text{overhead}$
	image tagged with current quaternion from ATE
20	picture 2 data transfer to flight computer, NAV
10	data processed by NAV to get centroids
	sent back to Murky
20	picture 1 data transfer to flight computer, NAV
10	data processed by NAV to get centroids
	sent back to Murky
-	centroid data available for star ID
-	if there is a star, make data available to ATE
69-71	sample time



## New ACS Software Architecture

- Tracking - Murky requests one image

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time (s)	event
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7	clear micas buffer
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	image request sent
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1-2	exposure $27 - 100ms$ + overhead
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	image tagged with current quaternion from ATE
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20	picture data transfer to flight computer, NAV
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10	data processed by NAV to get centroids
----	----------------------------------------

	sent back to Murky
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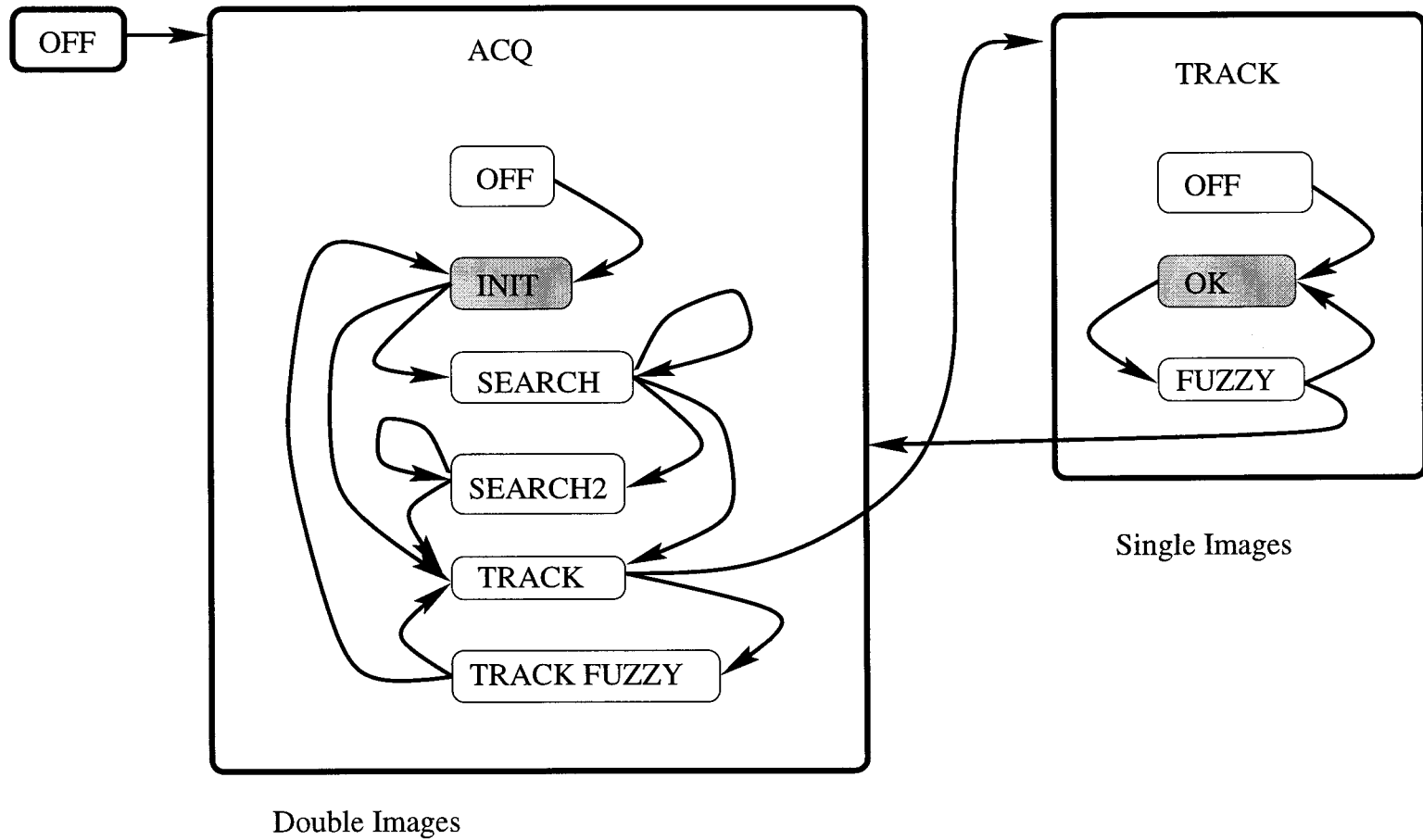
-	centroid data available for star ID
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-	if there is a star, make data available to ATE
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38-39	sample time
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# Murky Exec Modes



## Murky Exec Modes - Acquisition

- Acq Init - take one frame, 2 images, get Star ID results.  
Switch to Search can be disabled
  - if (star present)  
    switch to Acq Track
  - else  
    switch to Acq Search
- Acq Search - move to new attitude, take one frame, 2 images, get Star ID results.
  - if (good star present)  
    switch to Acq Track
  - else  
    continue
    - if the search is exhausted
  - if (bright enough star present)  
    switch to Acq Track
  - else  
    switch to Search 2

## Murky Exec Modes - Acquisition

- Acq Search2 - take one frame, 2 images, get Star ID results.
  - if (good star present)
    - switch to Acq Track
  - else
    - continue
    - if the search is exhausted
  - if (bright enough star present)
    - switch to Acq Track
  - else
    - increment search size, continue
- Acq Track - take one frame, 2 images, get Star ID results.
  - if (star present)
    - continue
  - else
    - switch to Acq Track Fuzzy
    - if long enough, switch to Track

## Murky Exec Modes - Acquisition

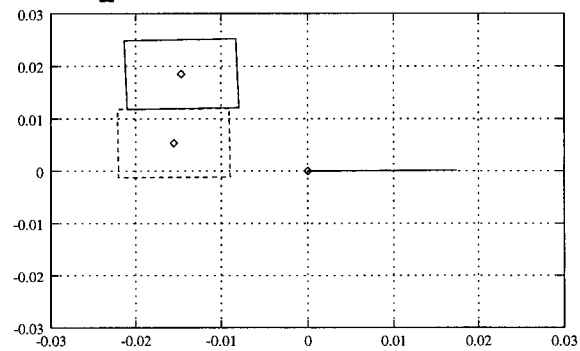
- Acq Track Fuzzy - take one frame, 2 images, get Star ID results.
  - if (star present)
    - switch to Acq Track
  - else
    - continue
    - if too long switch to Acq Init

## Murky Exec Modes - Track

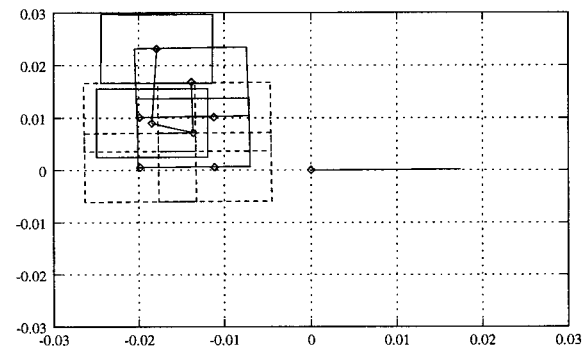
- Track Ok - take one image, get Star ID results.
  - if (star present)
    - continue
  - else
    - switch to Track Fuzzy
- Track Fuzzy - take one image, get Star ID results.
  - if (star present)
    - switch to Track Ok
  - else
    - continue
    - if too long switch to Acq Init

# Search Pattern

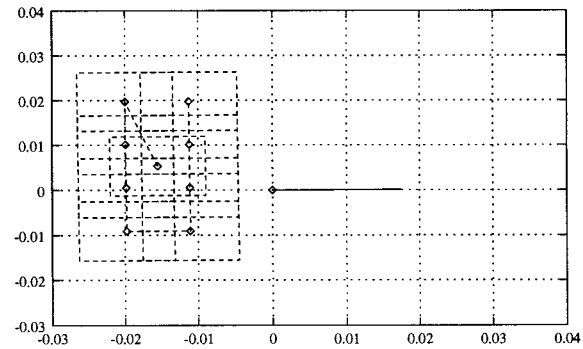
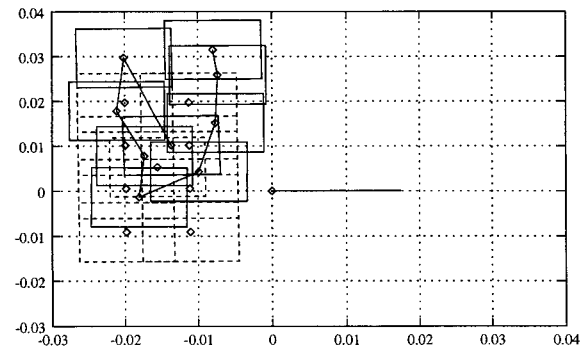
- A particular case  
Acq Init



## Search $2 \times 2$

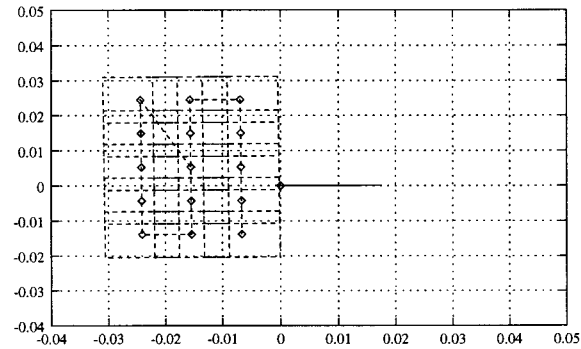
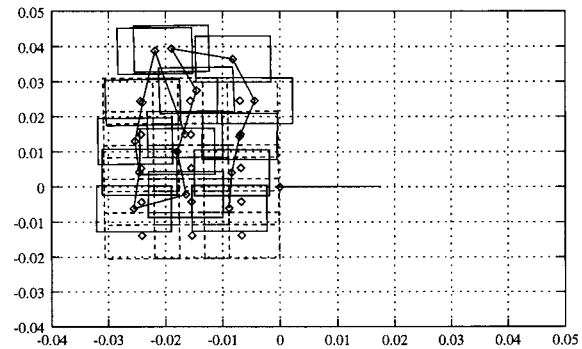


## Search2 $4 \times 2$

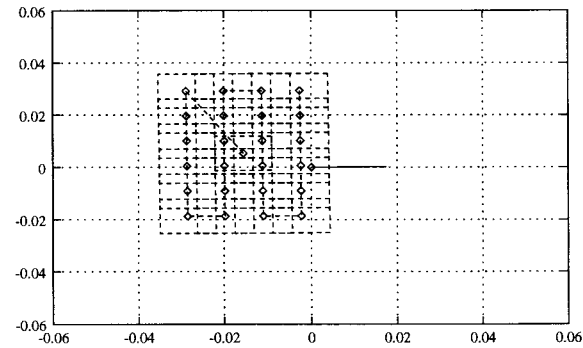
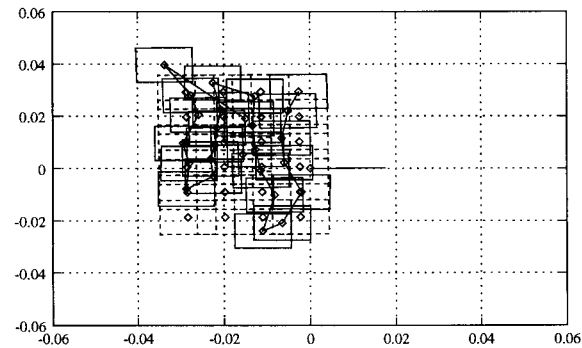


## Search Pattern (continued)

Search2  $5 \times 3$



Search2  $6 \times 4$





## Search Pattern (continued)

- Times

component	size	time
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Search	$2 \times 2$	568
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Search2	$4 \times 2$	1613
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Search2	$5 \times 3$	2814
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Search2	$6 \times 4$	4901
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- About 200 s per frame

## Reconciling Star and Sun

- We might not lock up on the right star
- We then have the star and sun in two frames
  - $v_J$  Catalog star
  - $v_b$  Measured star (MICAS)
  - $s_J$  Ephemeris sun
  - $s_b$  Measured sun (SSA); quantized to  $1/2^\circ$
  - $s'_b$  Estimated sun  $q_{ate}(s_J)$
- But do the sun cone angles agree  $v_J \cdot s_J = v_b \cdot s_b$  ?
- We modify the local star catalog (this can be enabled selectively in different modes)

$$c = v_b \cdot s_b, \quad s = \sqrt{1 - c^2},$$

$$s_1 = v_J - (v_J \cdot s_J)s_J,$$

$$v'_J = cs_J + ss_1.$$

## Reconciling Old and New Image Data

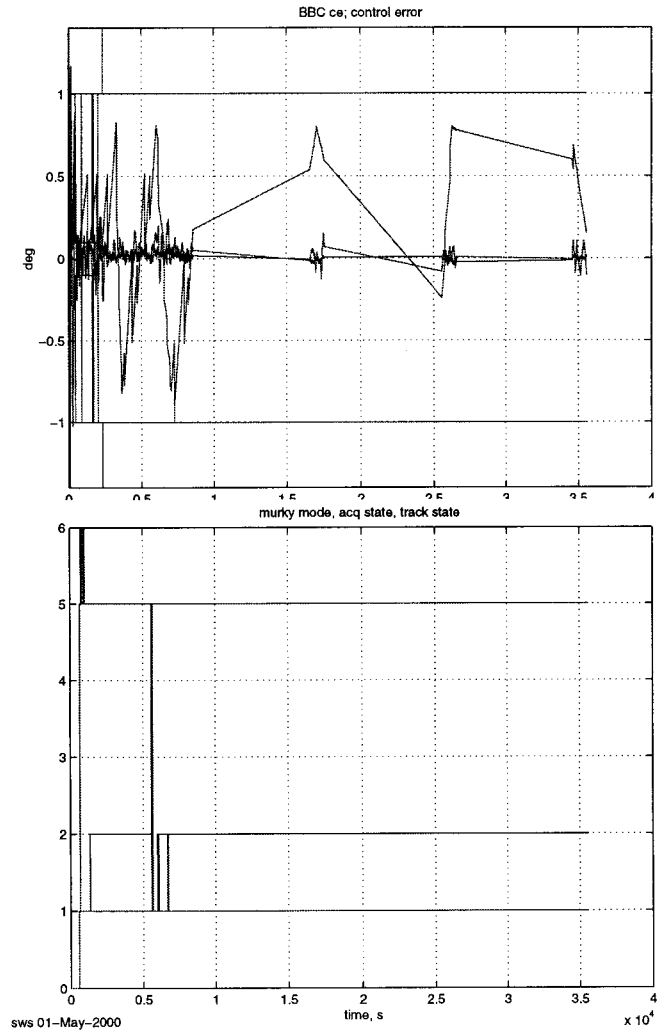
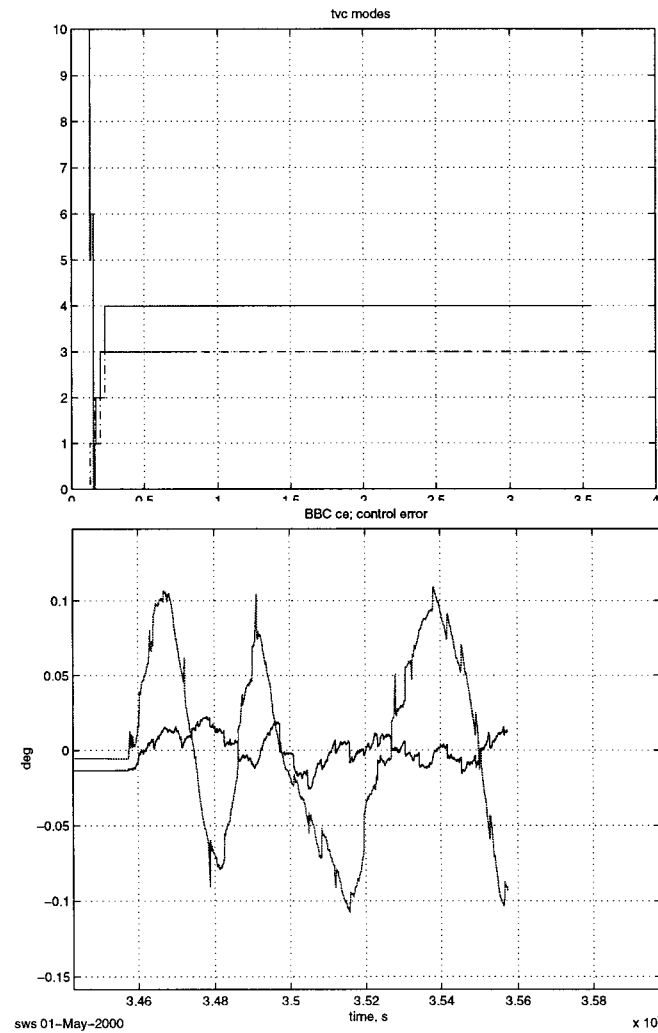
- If an old image provides an update to ATE, can we compare a new image to the old image?
- ATE keeps track of measurement updates (from MICAS, from everything) as a  $\delta q$  in J2000
- These  $\delta q$ 's can be passed on to Star ID, for updating old data.

## Simulation Results

- KludgeSim - non real time, Unix workstation, flight ACS code
  - Initialize using SRU, switch ATE to MICAS mode, turn on Murky, proceed from acquisition to track
  - Initialize using HGA inputs (not using full 30 $min$  light time delay)
  - Initialize using SRU, turn on TVC
- Testbed - real time, all flight software, flight computer
  - Initialize using SRU, switch ATE to MICAS mode, turn on Murky, proceed from acquisition to track
  - Initialize using SRU, turn on TVC

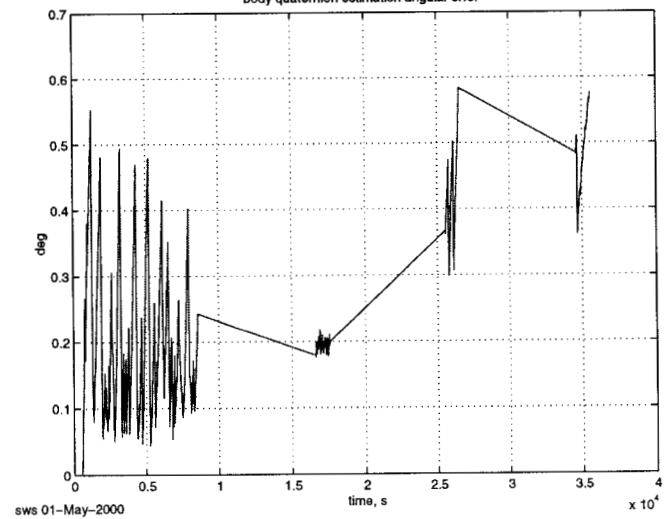
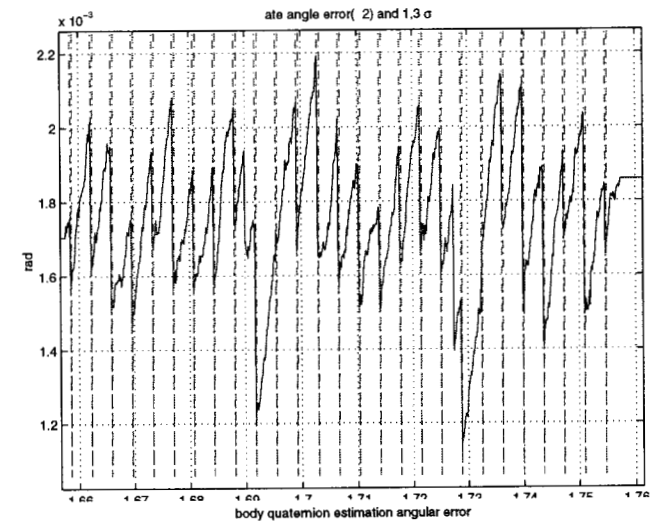
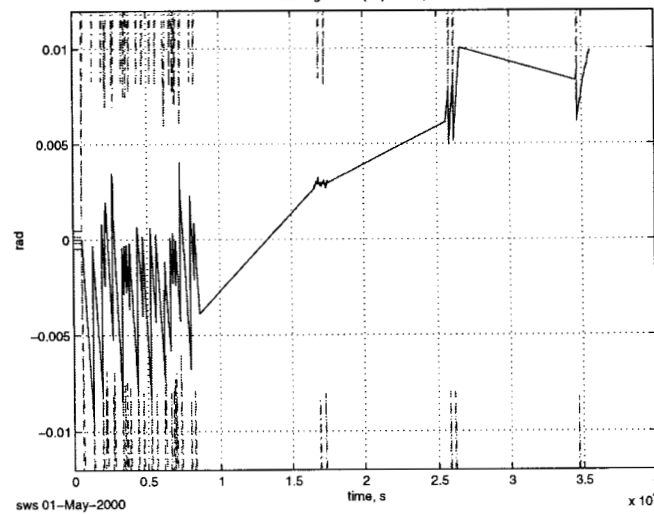
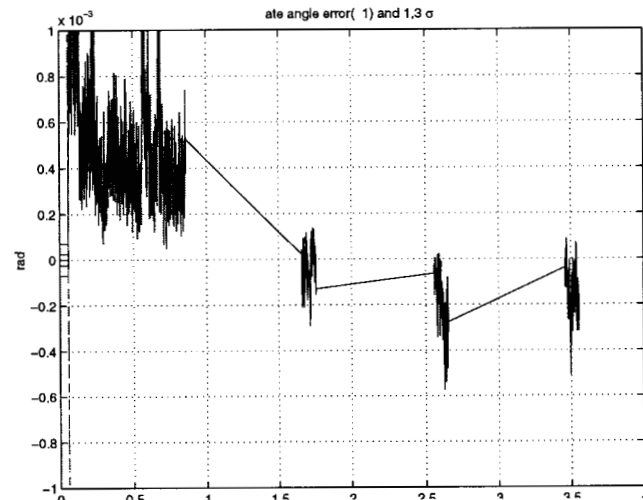
# Murky KludgeSim Results

## ○ TVC



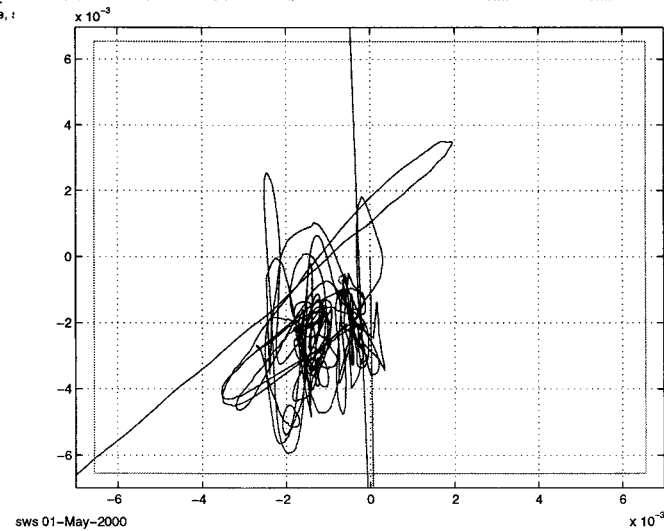
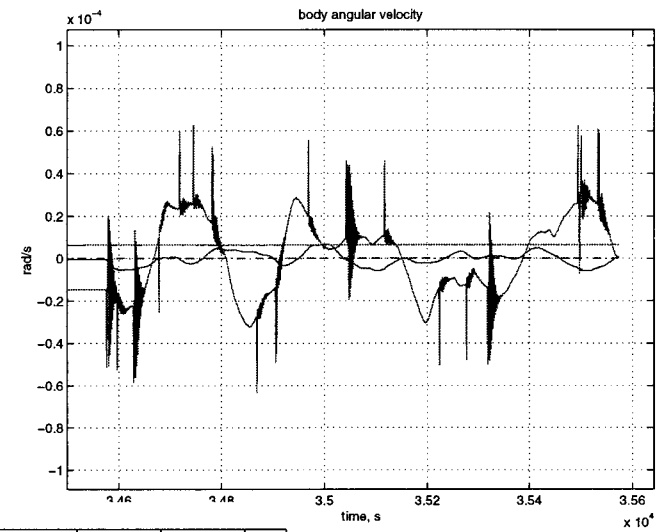
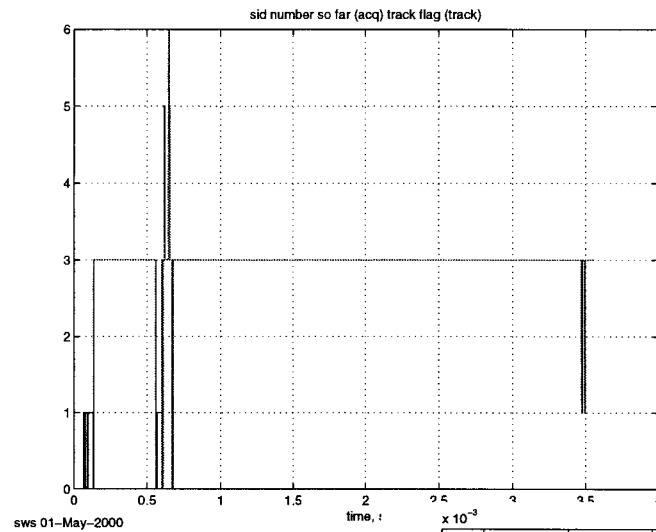
# Murky Kludgesim Results

- TVC (continued)



# Murky Kludgesim Results

- TVC (continued)



## Issues

- Bias estimate must be good or we can easily miss the star in the search
- Long term behavior as the sun moves
- Many parameters are available to tune, that have significant effects on the results
- We don't have complete knowledge of noise statistics